SB X2-1
Nitrate in Groundwater
Report to the Legislature

OVERVIEW AND KEY OUTCOMES

Thomas Harter
University of California Davis - SBX2-1 Team

June 9, 2011

Department of Land, Air, and Water Resources
University of California, Davis
Contact: ThHarter@ucdavis.edu

UCD Project Team Leaders

- Thomas Harter (PI), Subsurface Hydrology
- Jeannie Darby, Water Treatment
- Graham Fogg, Subsurface Hydrology
- Richard Howitt, Agricultural Economics
- Katrina Jessoe, Water Quality Economics
- Jay Lund, Water Resources Management
- Jim Quinn, Spatial Data Mgmt. in Environmental Policy
- Stu Pettygrove, Soils and Nutrient Management
- Tom Tomich, Agricultural Sustainability Institute
- Joshua Viers, Spatial Data Management in Environmental Sciences

FUNDING PROVIDED BY:

- **Proposition 84 / SB X 2-1 => CDPH => SWRCB**

UCD Project Team

- Aaron King
- Allan Hollander
- Alison McNally
- Anna Fryjoff-Hung
- Cathryn Lawrence
- Daniel Liptzin
- Dylan Boyle
- Elena Lopez
- Giorgos Kourakos
- Holly Canada
- Josue Medellin-Azuara
- Kristin Dzurella
- Kristin Honeycutt
- Mimi Jenkins
- Nate Roth
- Todd Rosenstock
- Vivian Jensen

- …many undergraduate students….

Timeline

- Data collection and analysis – 2nd Quarter 2011
- Economic and policy analysis – 3rd Quarter 2011
  - **2nd ITF Meeting – May 3, 2011**
- Draft report – September 2011
  - **3rd ITF Meeting – October 2011**
- Final report – December 2011
- SWRCB Report to Legislature – April 2012
- Directed follow-up studies – April 2013

Motivation

- Nitrate most common groundwater pollutant
- Tulare Lake Basin and Salinas Valley among most affected groundwater basins in CA
- Domestic well water typically untreated / unknown quality
- High nitrate costly to treat for small / disadvantaged communities

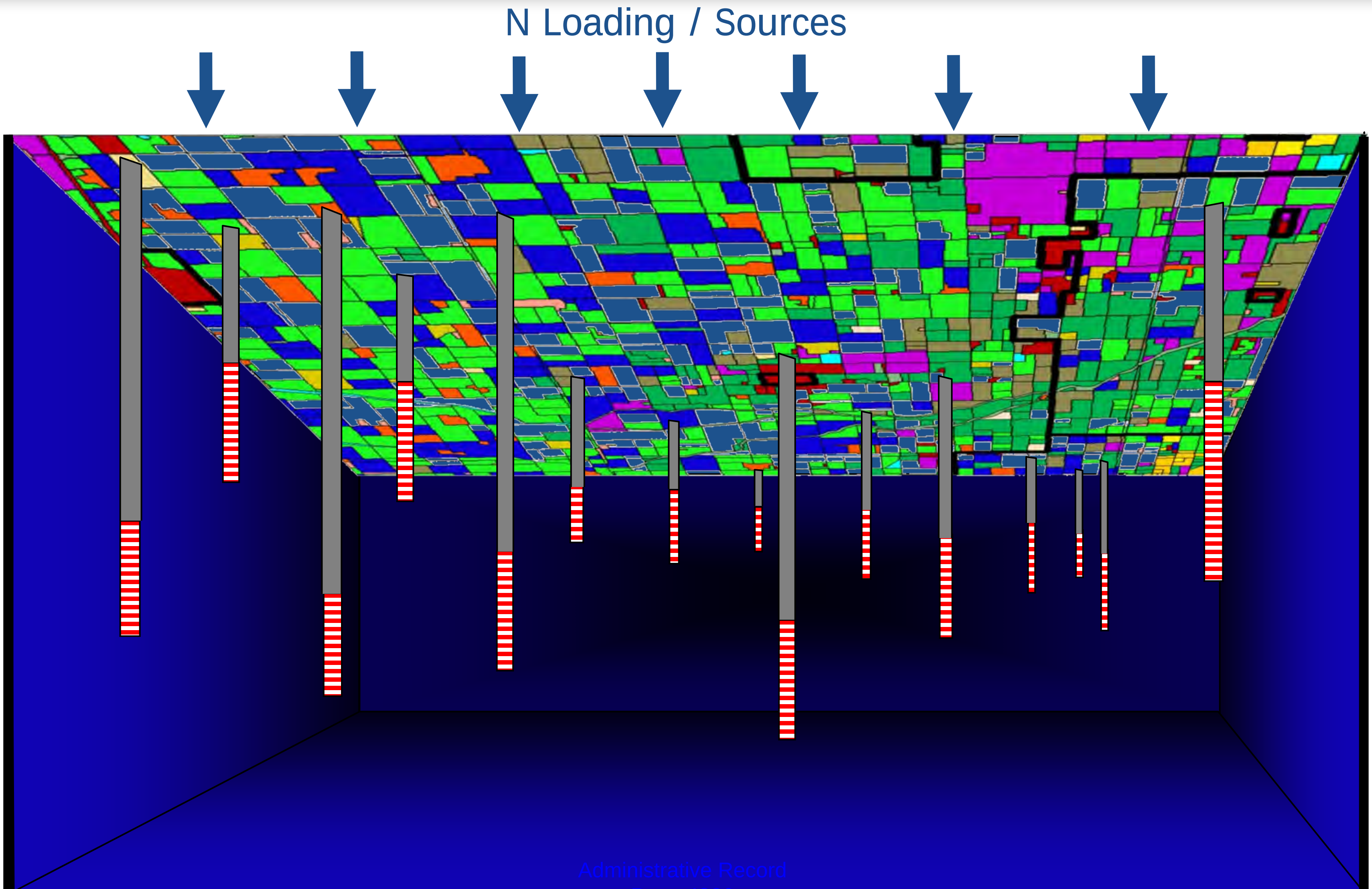
How can this be best fixed?

Project Area

Irrigated Areas

Landuse

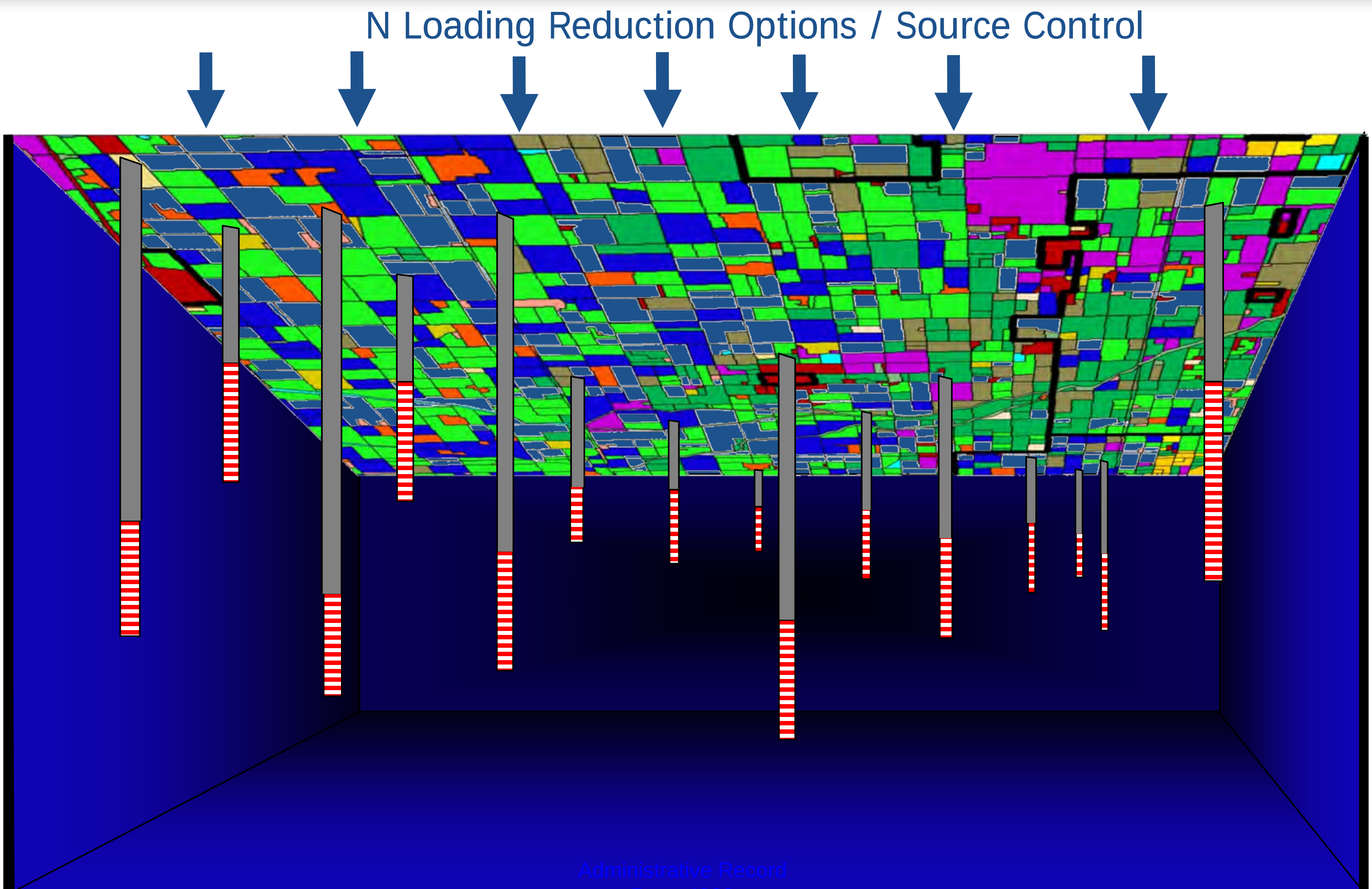
Key Study Outcomes: Assessment



Key Study Outcomes: Assessment

Nitrate distribution in groundwater / spatial and temporal trends

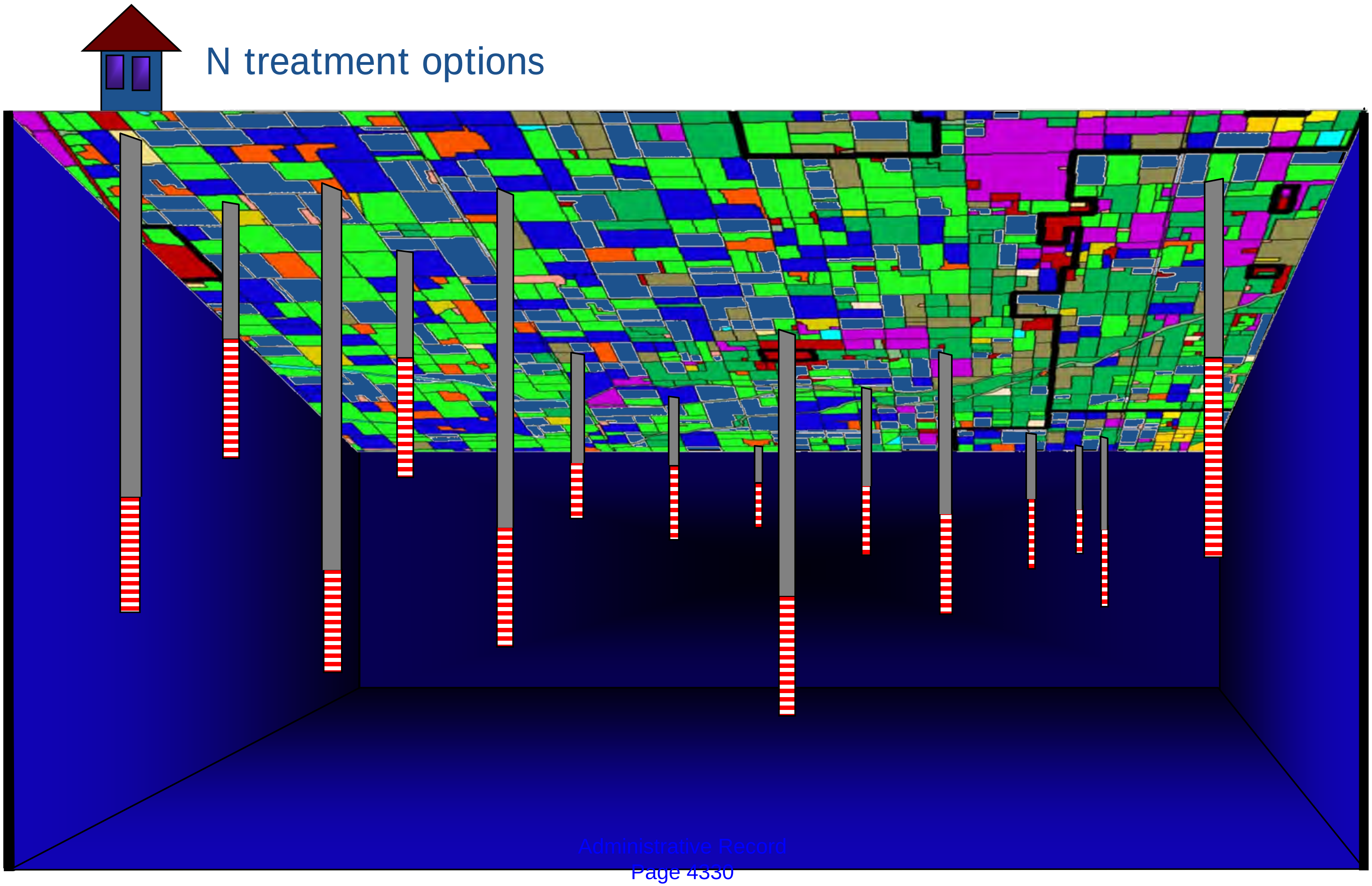
Key Study Outcomes: Actions



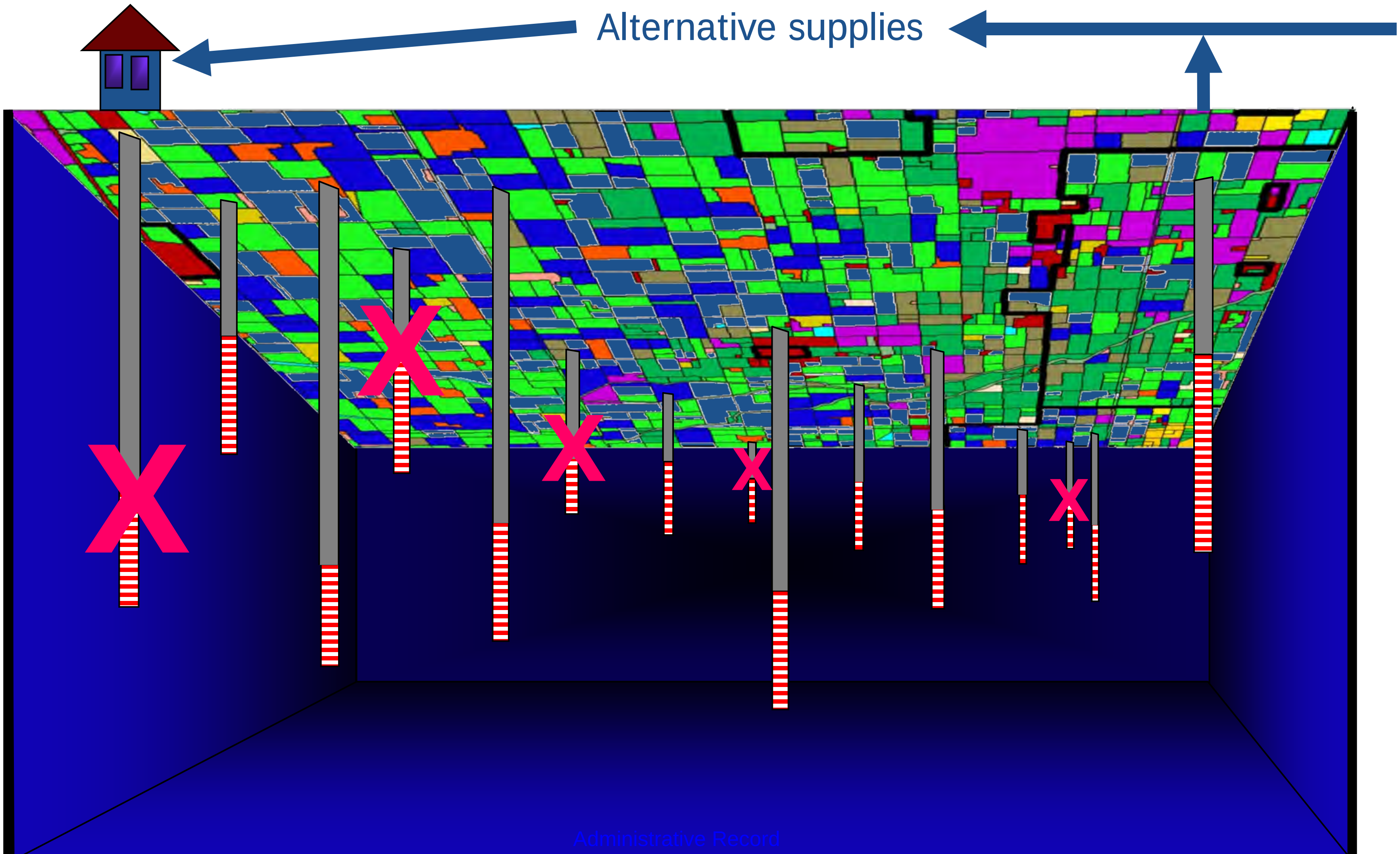
Key Study Outcomes: Actions

Remediation of groundwater

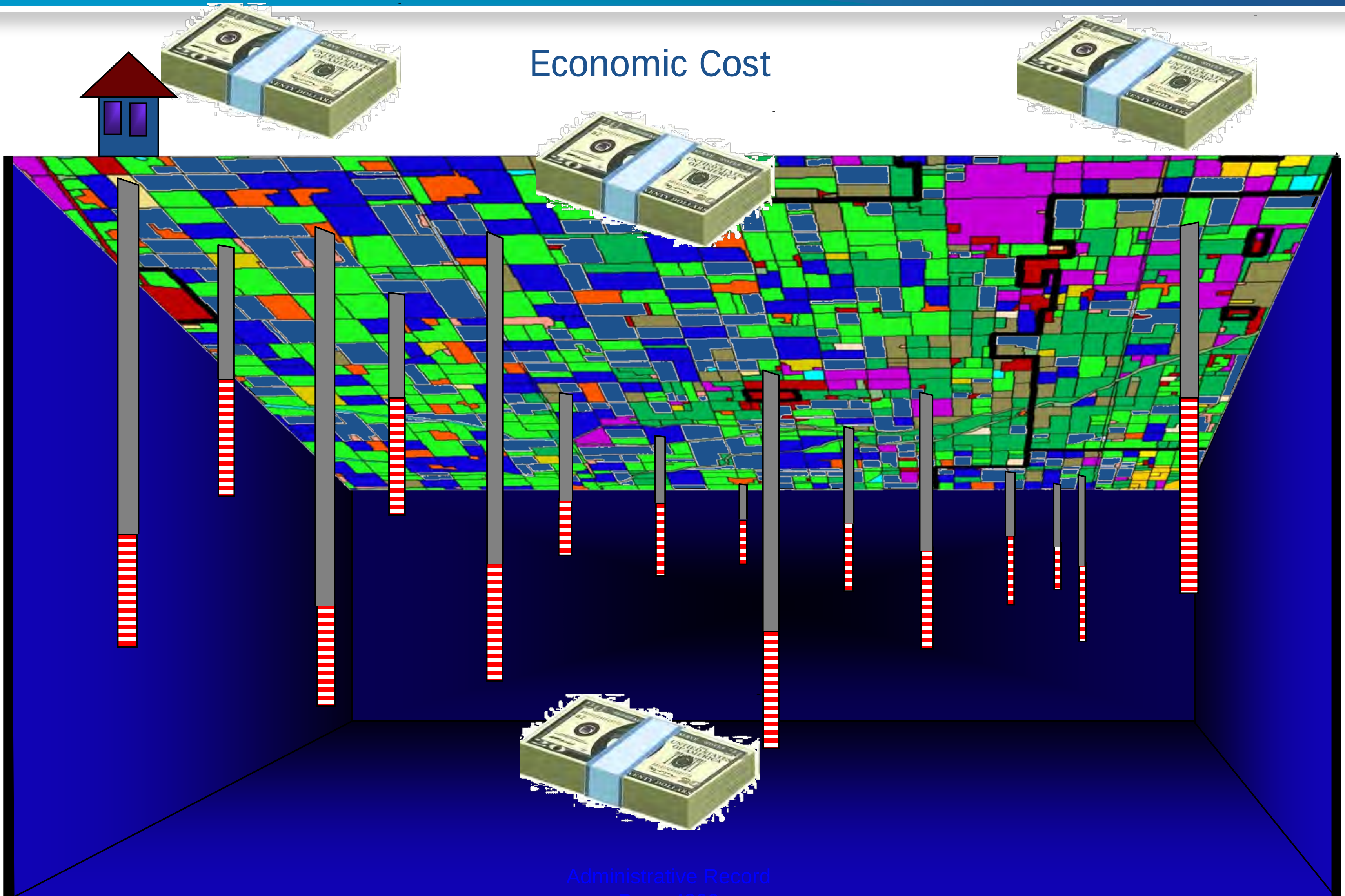
Key Study Outcomes: Actions



Key Study Outcomes: Actions

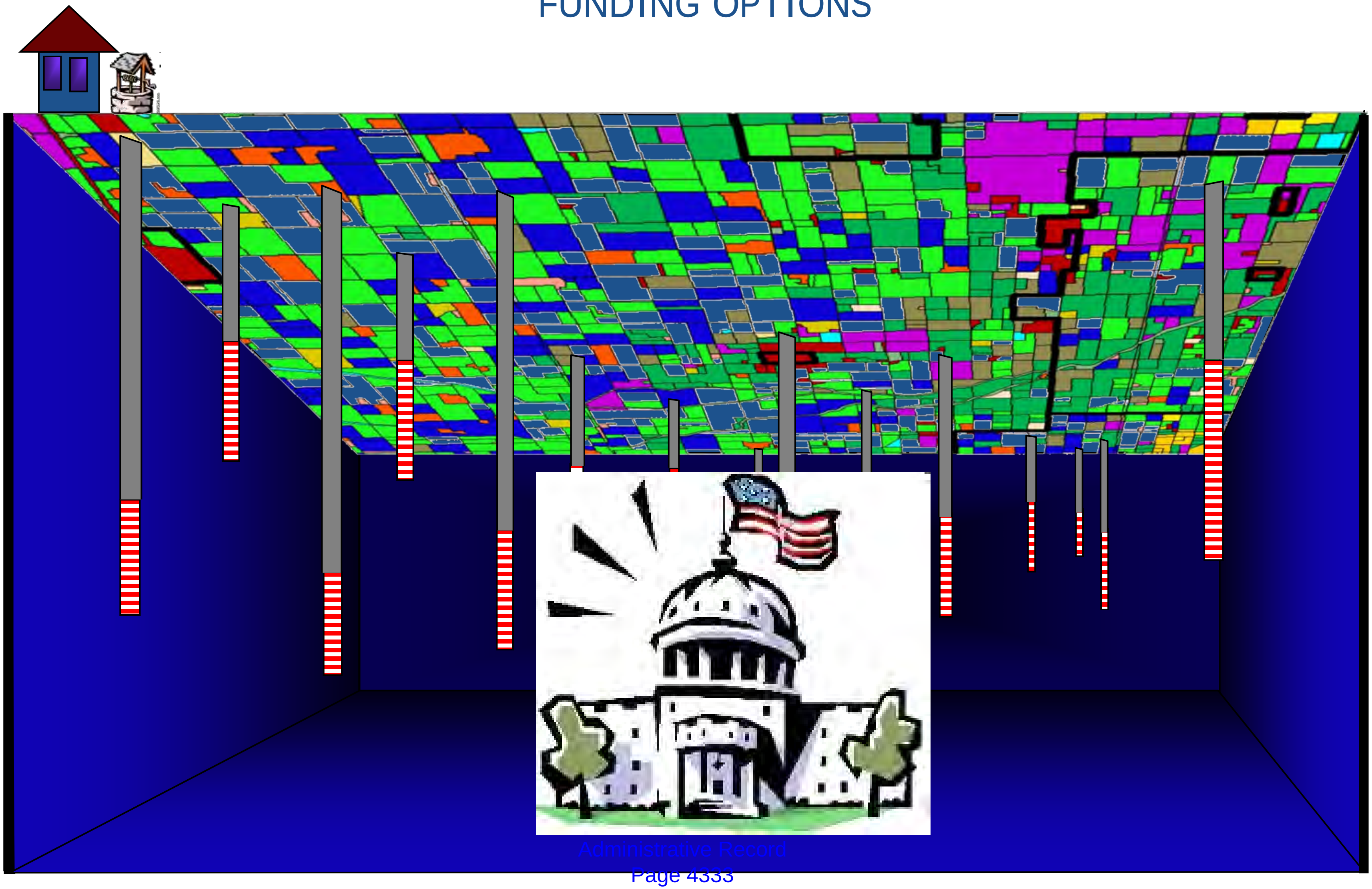


Key Study Outcomes: Costs



Key Study Outcomes: Funding

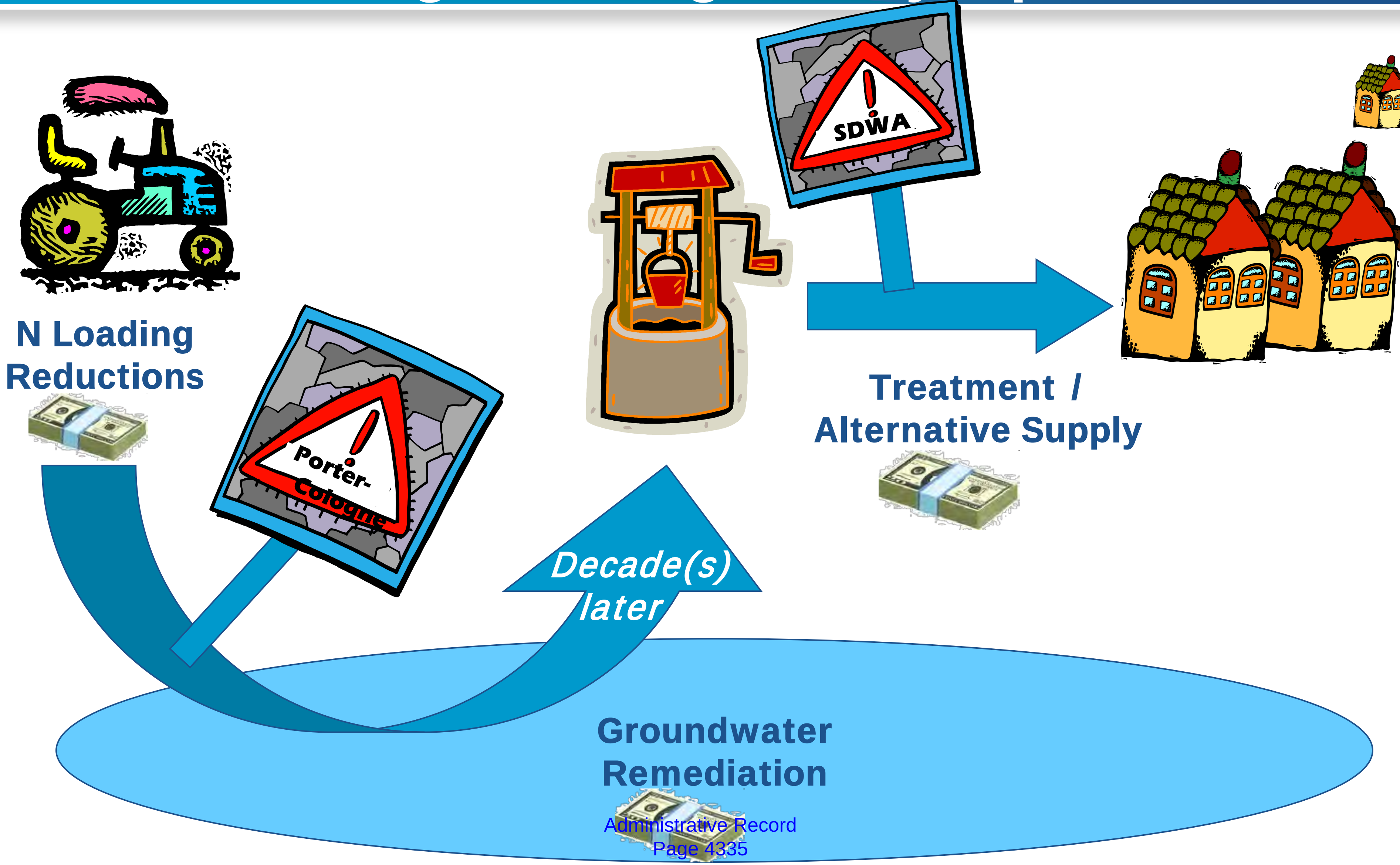
FUNDING OPTIONS



Key Messages

- Nitrate problem will likely worsen and not improve for several decades
- Largest regional sources are agricultural fertilizers and animal wastes; other sources are locally relevant
- Nitrogen loading reductions possible, but will take decades to benefit drinking water sources
- Short-term solutions are blending, treatment, and alternative water supplies
- Treatment is unaffordable for most small communities
- Promising funding options, incentives, and regulatory tools are identified
- Incoherence and inaccessibility of data prohibit better and continuous assessment

Framework for Funding and Regulatory Options



Overview: Contamination Mgmt.

Landuse Nitrate Loading

Assess landuse:
historic – current - future

Loading Reduction Options

Identify improved agricultural practices
Identify reduction options for other sources

Water Quality Data

Develop water quality database
Analyze water quality
Modeling tool to predict future nitrate

GOAL

Assess options to address the nitrate problem through source reduction and/or remediation

Overview: Drinking Water Mgmt.

Water Quality Data

- Assess nitrate loading to groundwater
- Assess nitrate occurrence
- Characterize water quality

Vulnerable Populations

- Characterize vulnerable populations
- Locate disadvantaged communities

Solutions

- Alternative water supply options
- Nitrate treatment options

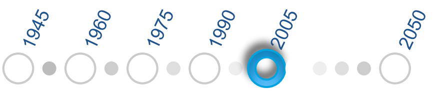
GOAL

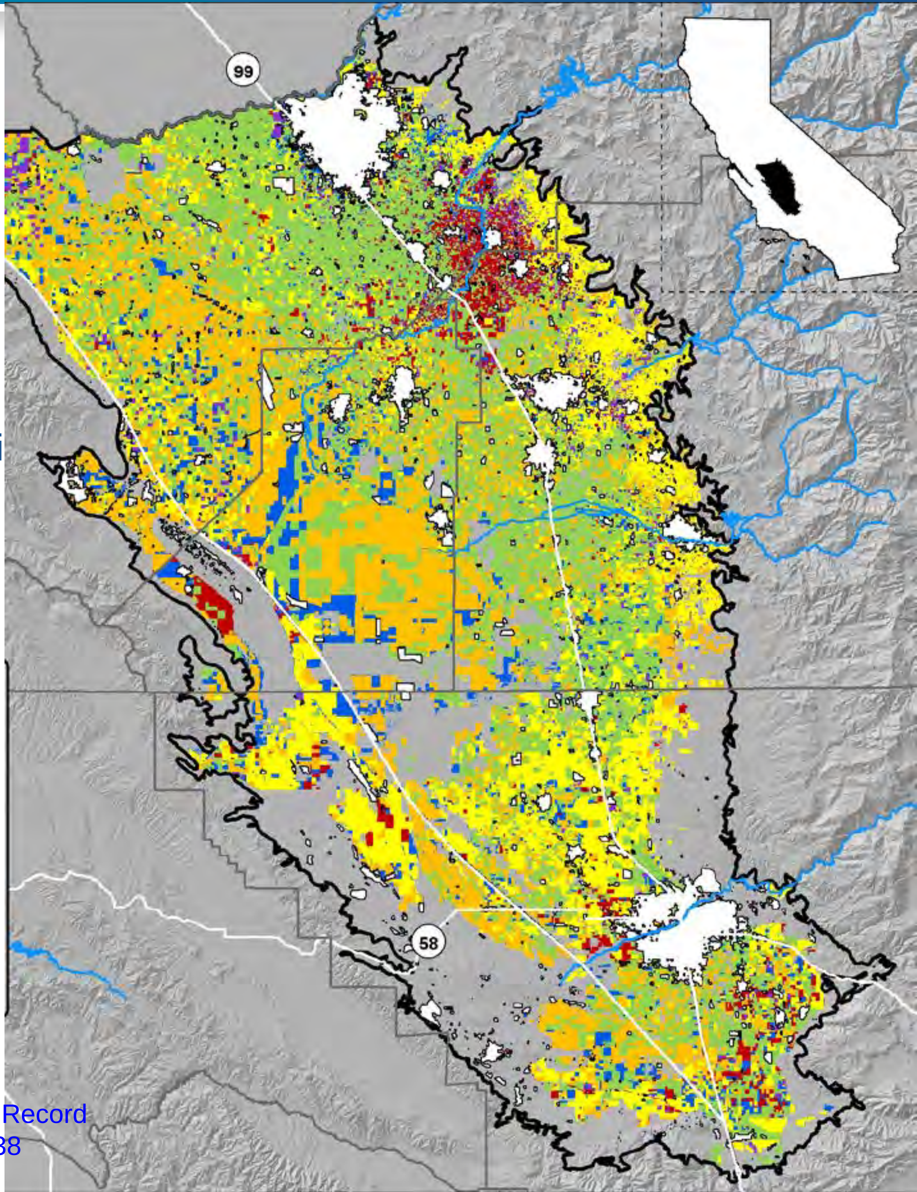
Assess options to address the nitrate problem with consideration of location, water quality, system size, feasibility and cost

N Loading, Fertilizer

- Time Frame(s):
  - 2000-2010
- Methods:
  - Land Use Estimates (CAML 2.0)
    - Farmland Mapping Monitoring Program
    - DWR by county (date varies)
    - Cropland Data Layer from National Agri
    - CDF Multisource Land Cover (2002)
- Results:

Study Basin	Potential N Load Leached (Mg/yr)
Salinas Valley	9,688
Tulare Lake Basin	84,775





Fertilizer Loading Reduction Necessary to ~ Meet MCL

Surface Discharges

Metric Tons (Mg) of N Applied Annually in facility discharge

	WWTP (90%)	WWTP (est. 100%)	FP (reported)	FP (est. max)
By County				
Fresno	2,344	2,604	303	674
Kern	913	1,014	455	1,010
Kings	121	134	167	372
Tulare	1,583	1,759	91	203
Monterey	313	348	15	33
Basin				
TLB	4,961	5,511	1,016	2,259
SVB	313	348	15	33
Total	5,274	5,859	1,031	2,292

These are preliminary estimates and do NOT include applied solids.

Preliminary

dairy N loading to land application:	114,000 Mg/yr
dairy N loading directly via corrals and lagoons:	1,000 Mg/yr

Maximum: Non-Dairy

Maximum: Non-Dairy, Dairy

TLB Nitrate View to SE

next view

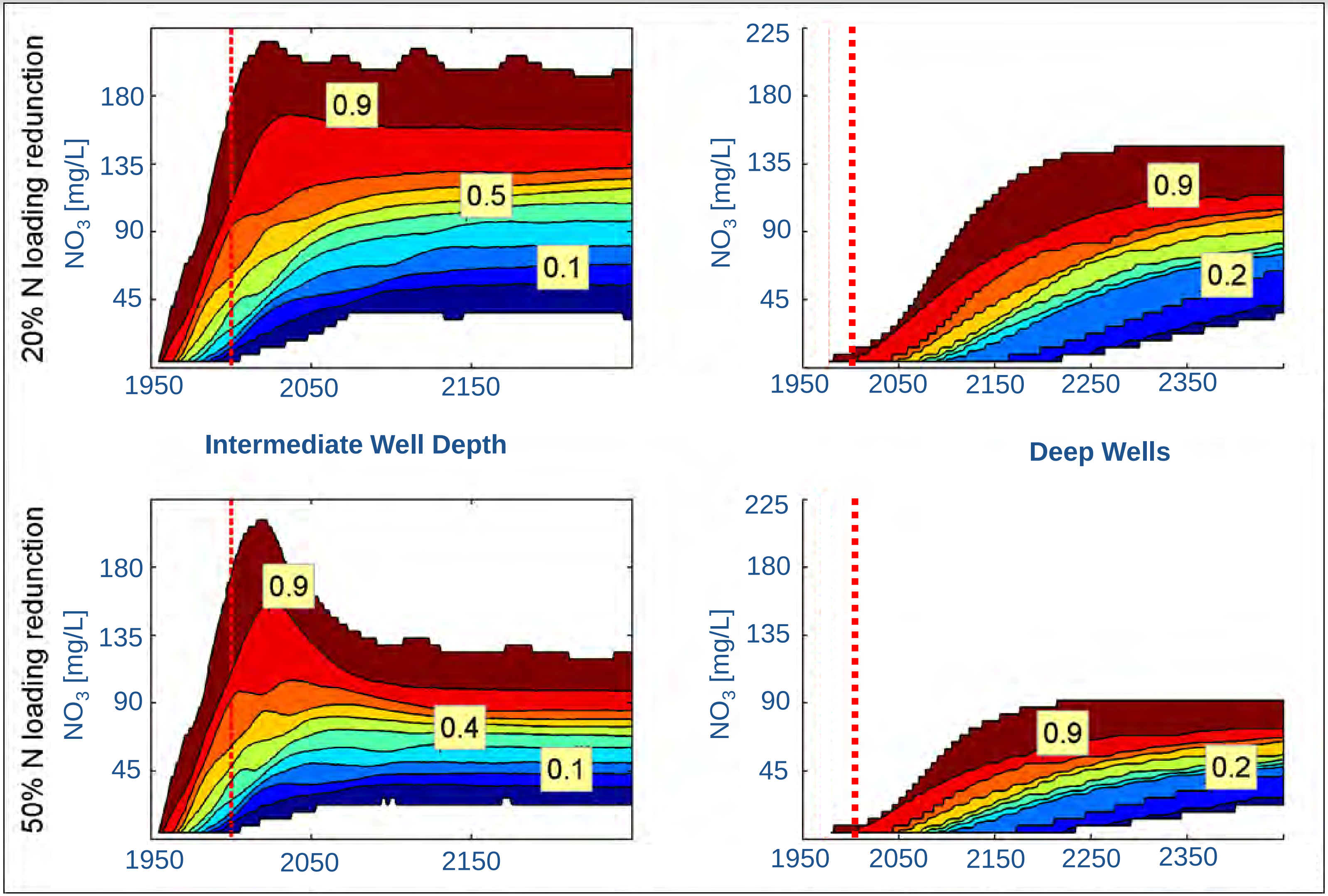
TLB Nitrate View to SSE

Nitrate in Wells: Long-Term Trends

	Mean Change [mg/L/yr]	Conf. Interval -95%	Conf. interval +95%
Tulare Lake Basin (Tulare County) Public Supply Wells, 1970s-current[1]	0.27 (0.41)	0.17 (0.22)	0.36 (0.59)
Salinas Valley Public Supply Wells, 1970s-current[1]	0.53	0.31	0.77
Salinas Valley Dedicated Monitoring Wells, 1990-current	2.04	1.25	2.82

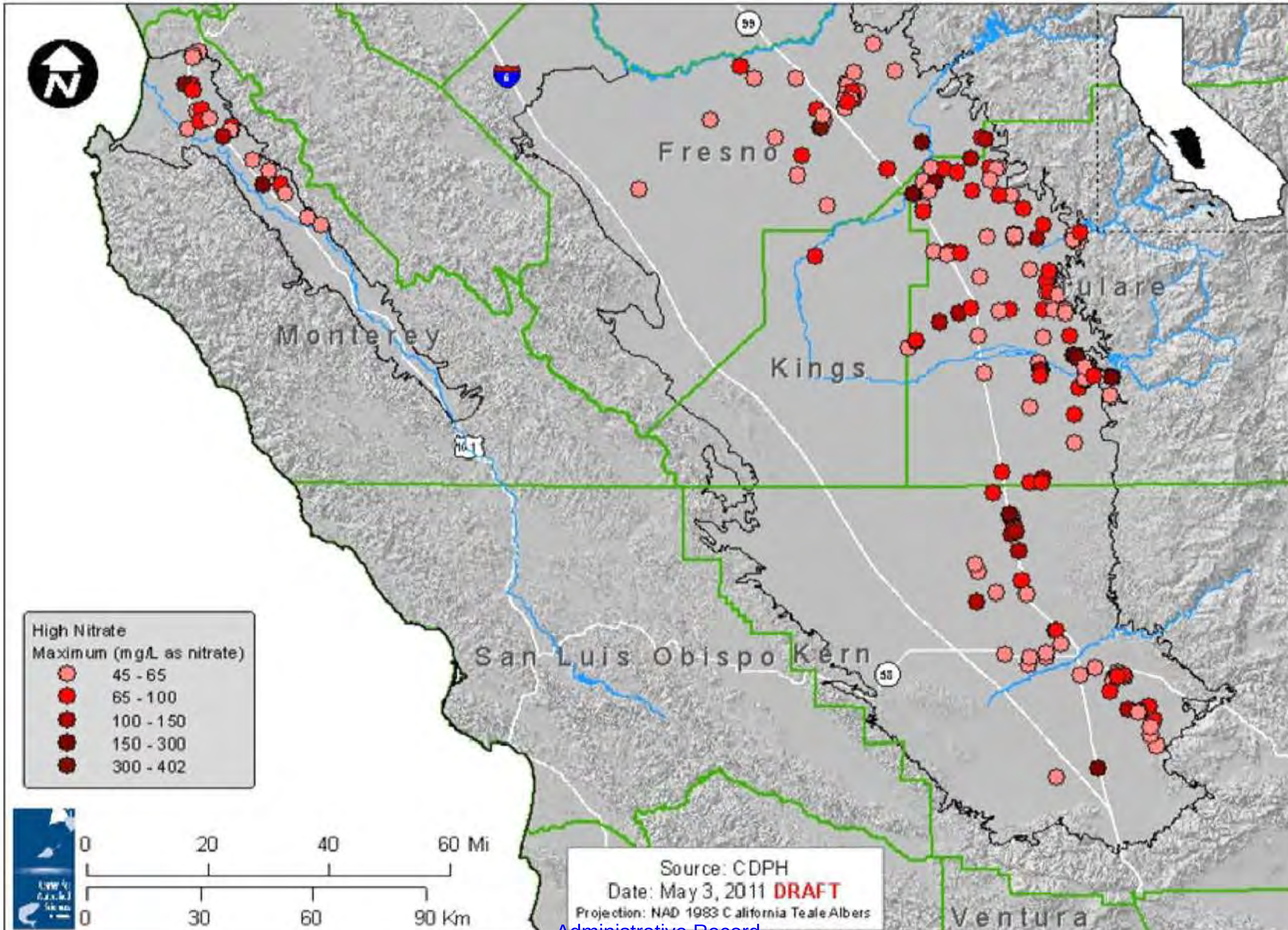
[1]underlying data: all public water supply well data

Future model predictions

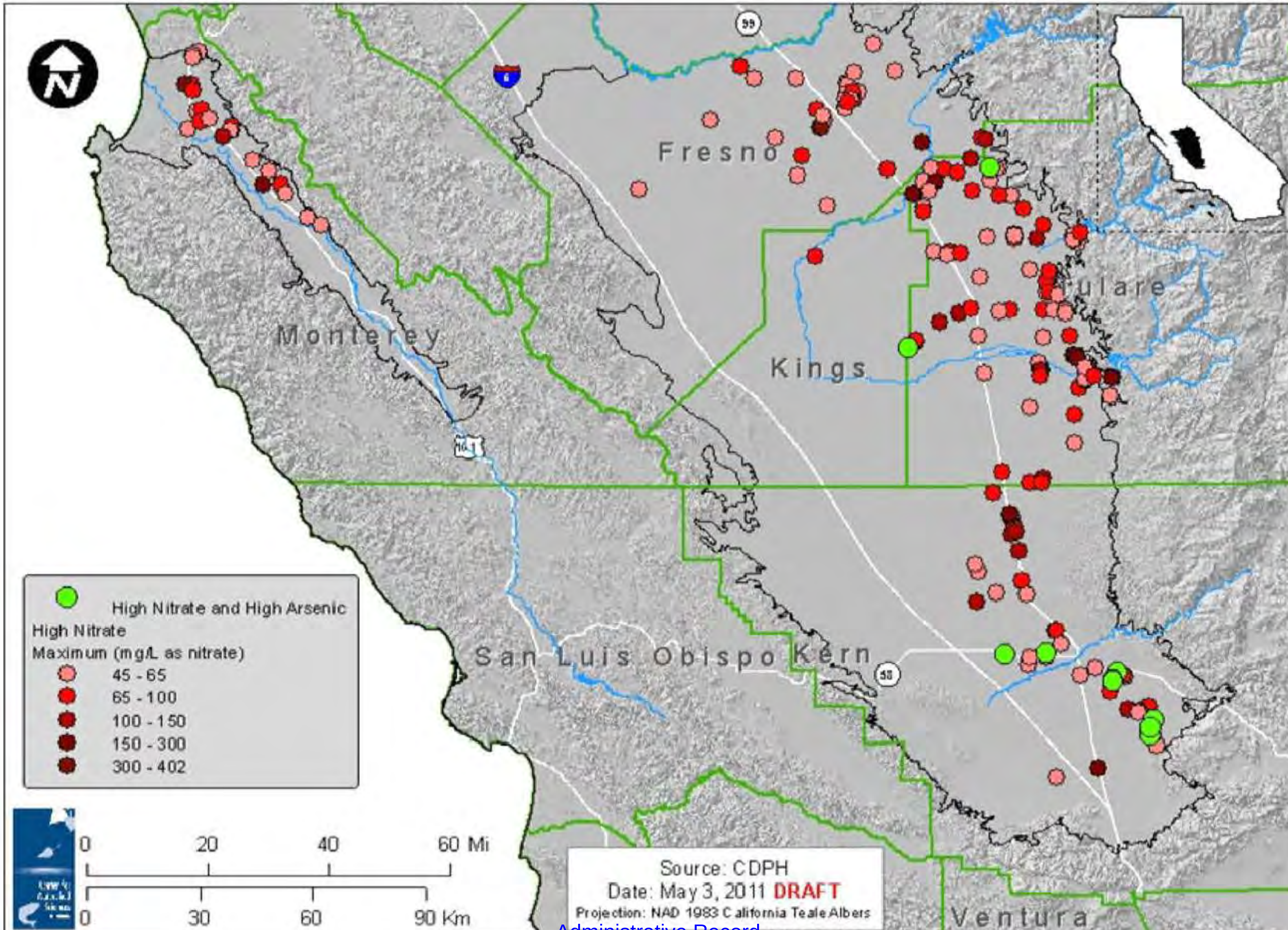


Preliminary modeling results for conceptual illustration only,
subject to further model adjustment and calibration

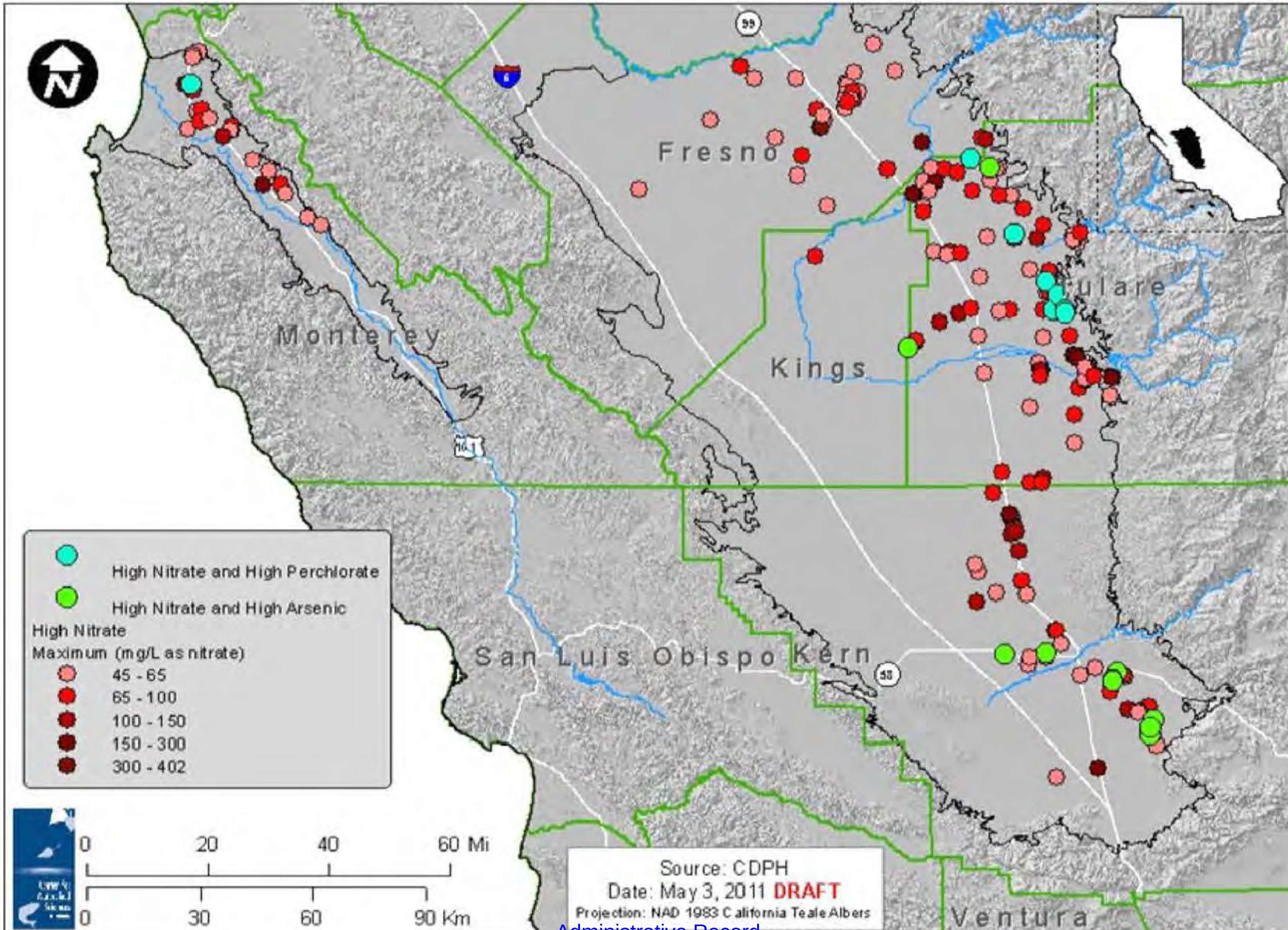
Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



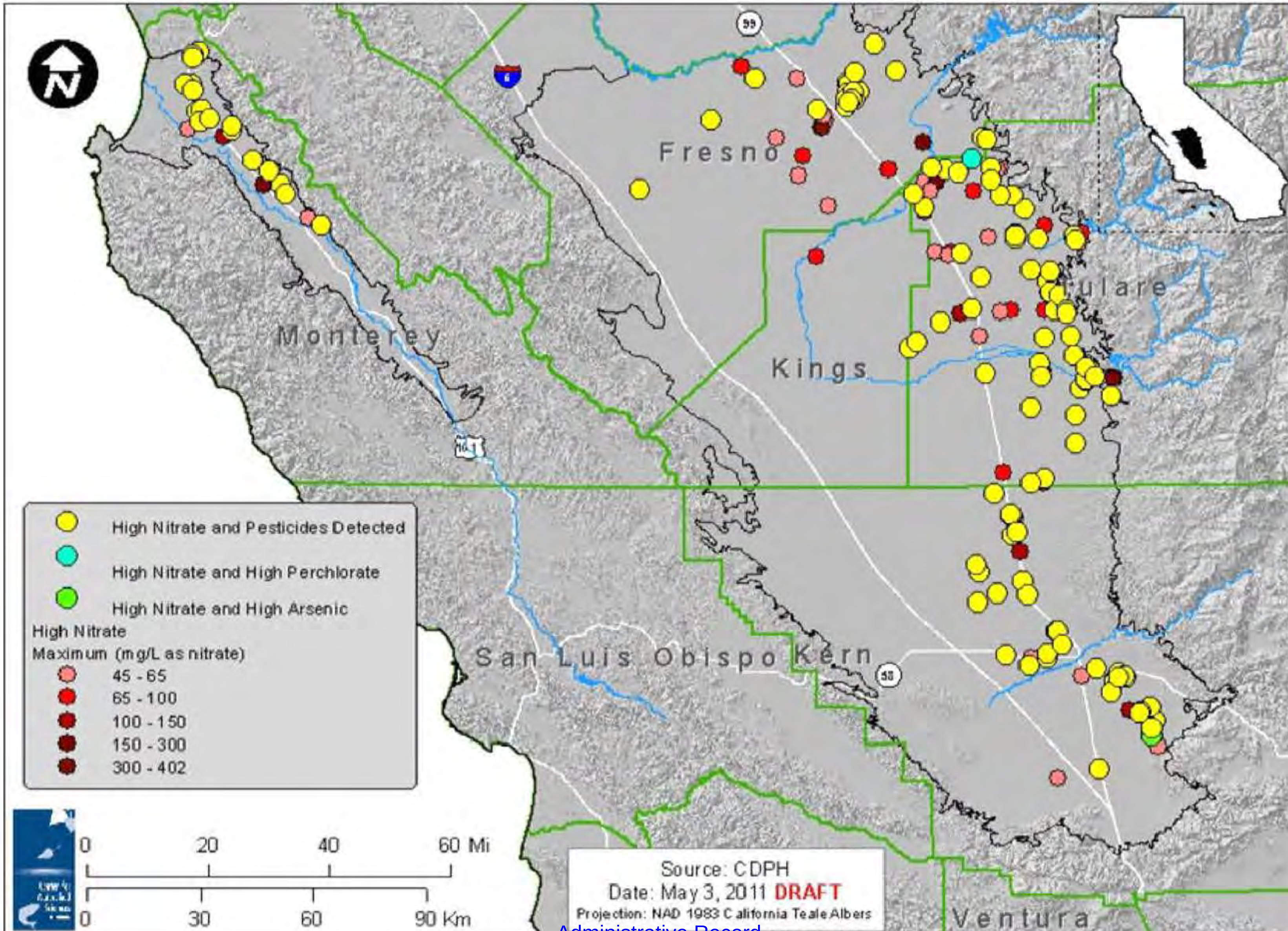
Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



Overview

Water Quality Data

Assess nitrate occurrence
Characterize water quality

Vulnerable Populations

Characterize vulnerable populations
Locate disadvantaged communities

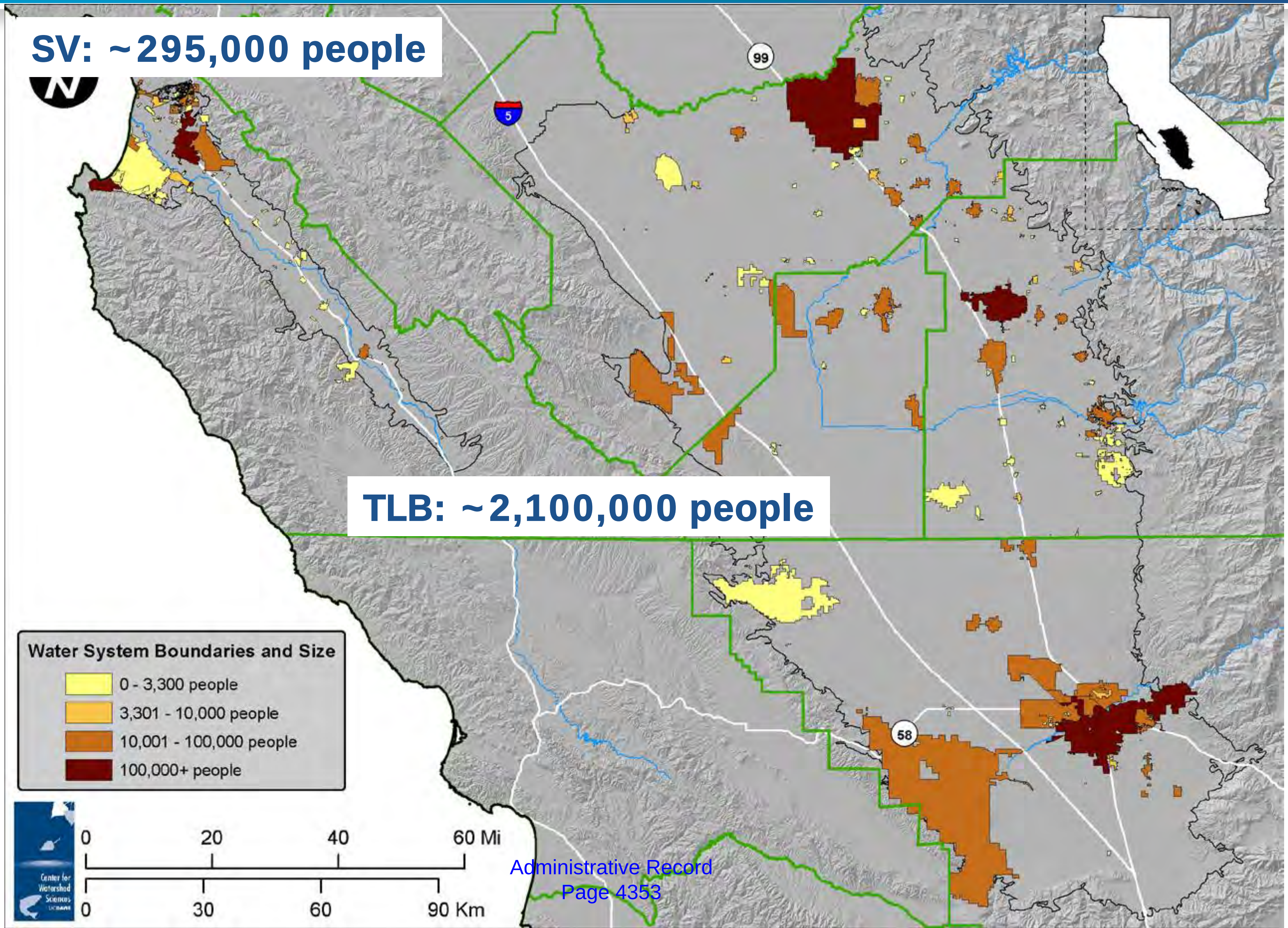
Solutions

Alternative water supply options
Nitrate treatment options

GOAL

Assess options to address the nitrate problem with consideration of location, water quality, system size, feasibility and cost

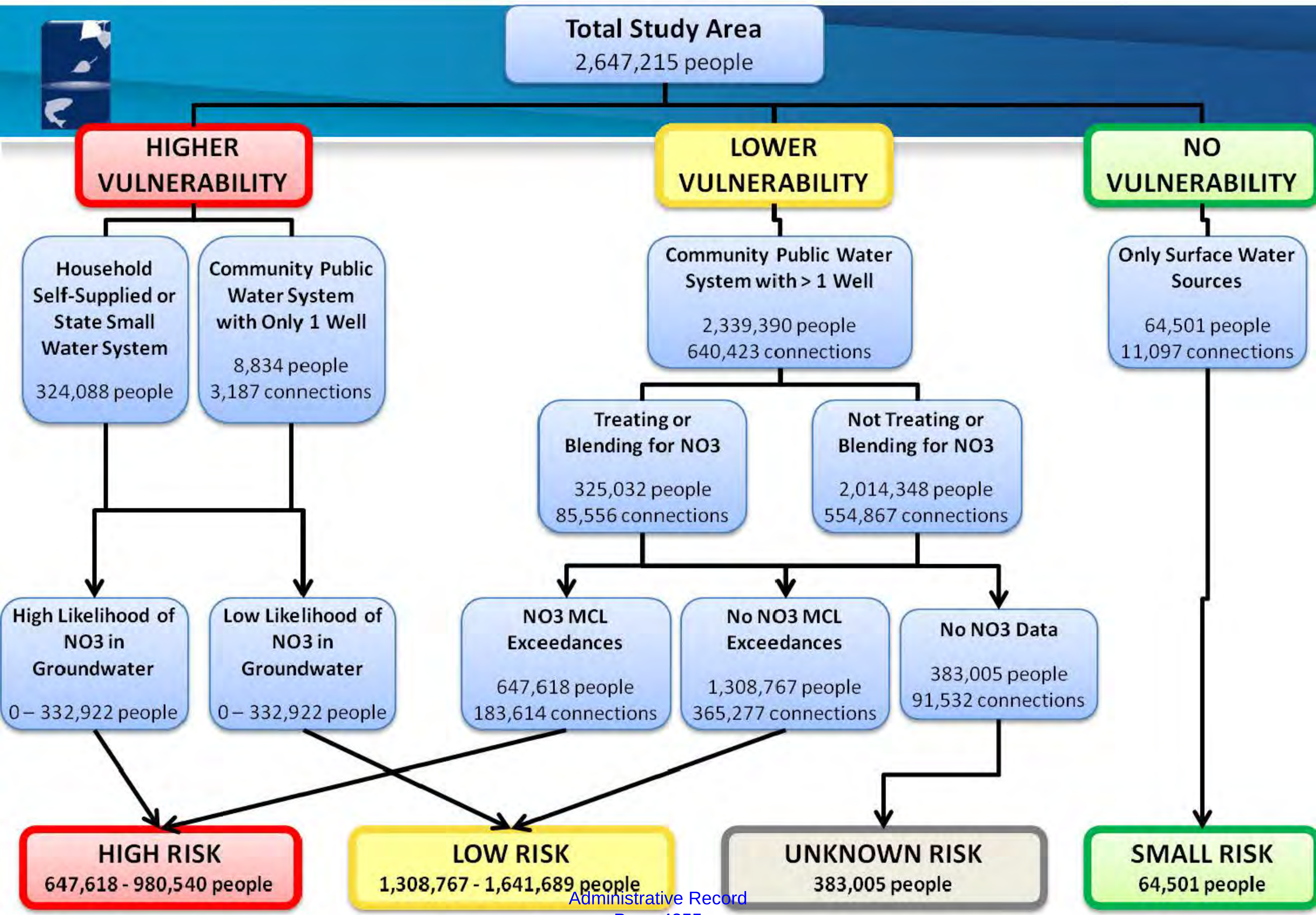
Community Water Systems



Household Self-Supplied Systems

SV: ~32,000 people

TLB: ~300,000 people


Total Study Area
2,647,215 people
HIGHER VULNERABILITY
LOWER VULNERABILITY
NO VULNERABILITY
Household Self-Supplied or State Small Water System
324,088 people
Community Public Water System with Only 1 Well
8,834 people
3,187 connections
Community Public Water System with > 1 Well
2,339,390 people
640,423 connections
Only Surface Water Sources
64,501 people
11,097 connections
Treating or Blending for NO3
325,032 people
85,556 connections
Not Treating or Blending for NO3
2,014,348 people
554,867 connections
High Likelihood of NO3 in Groundwater
0 – 332,922 people
Low Likelihood of NO3 in Groundwater
0 – 332,922 people
NO3 MCL Exceedances
647,618 people
183,614 connections
No NO3 MCL Exceedances
1,308,767 people
365,277 connections
No NO3 Data
383,005 people
91,532 connections
HIGH RISK
647,618 - 980,540 people
LOW RISK
1,308,767 - 1,641,689 people
UNKNOWN RISK
383,005 people
SMALL RISK
64,501 people

Overview

Water Quality Data

Assess nitrate occurrence
Characterize water quality

+

Vulnerable Populations

Characterize vulnerable populations
Locate disadvantaged communities

+

Solutions

Alternative water supply options
Nitrate treatment options

GOAL

Assess options to address the nitrate problem with consideration of location, water quality, system size, feasibility and cost

Alternative Water Supply Options

- **Improve Existing Source**
  - Blending+
  - Drill Deeper or New Well+
  - Community Treatment
  - Household Treatment*
  - Centralized Management of POU/POE

- **Create Alternative Supplies**
  - Switch to Treated Surface Water
  - Consolidation
  - Trucked Water*
  - Bottled Water

- **Relocate Households**

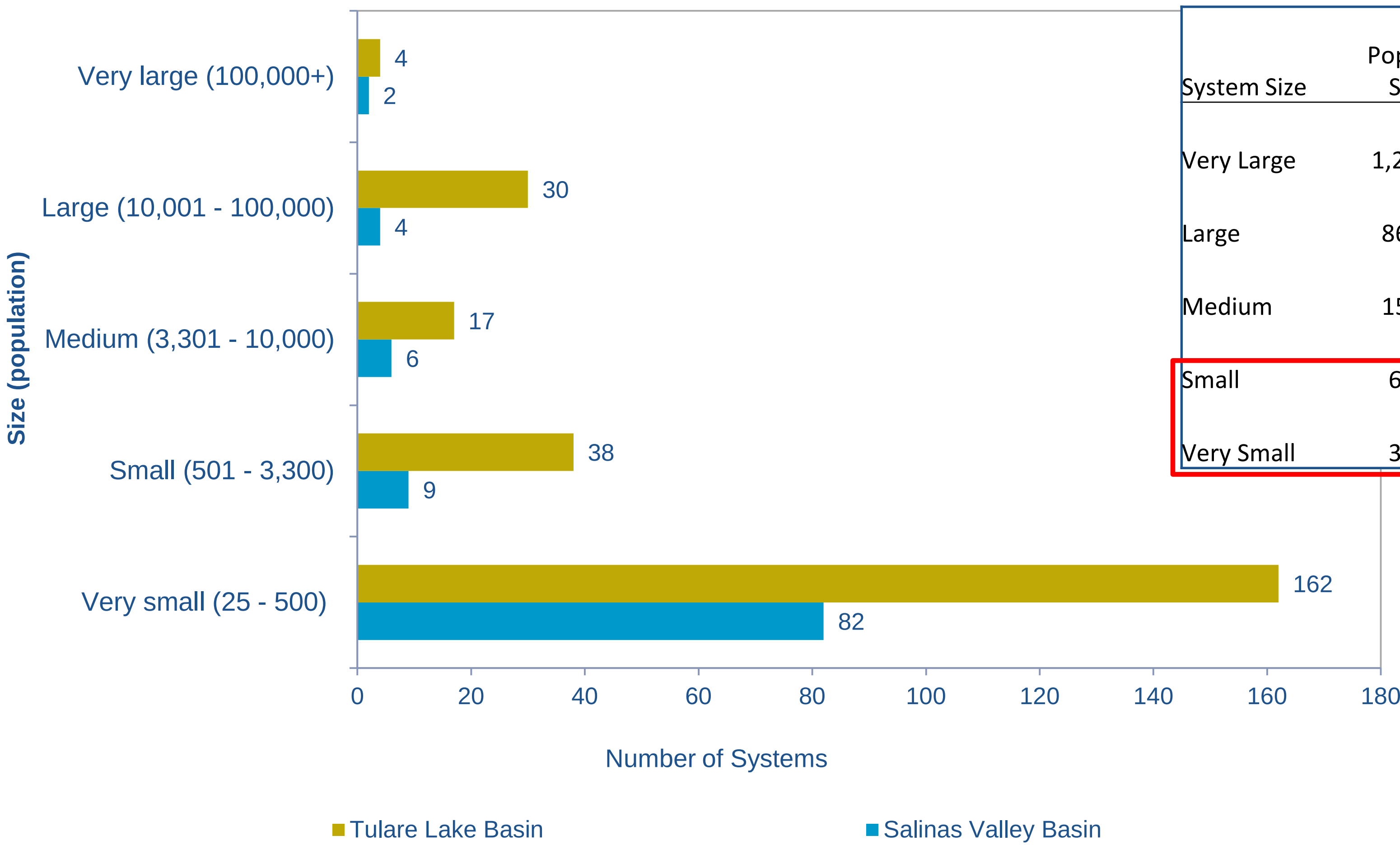
Ancillary Activities:

+Well Water Quality Testing

*Dual System

Regionalization/Consolidation

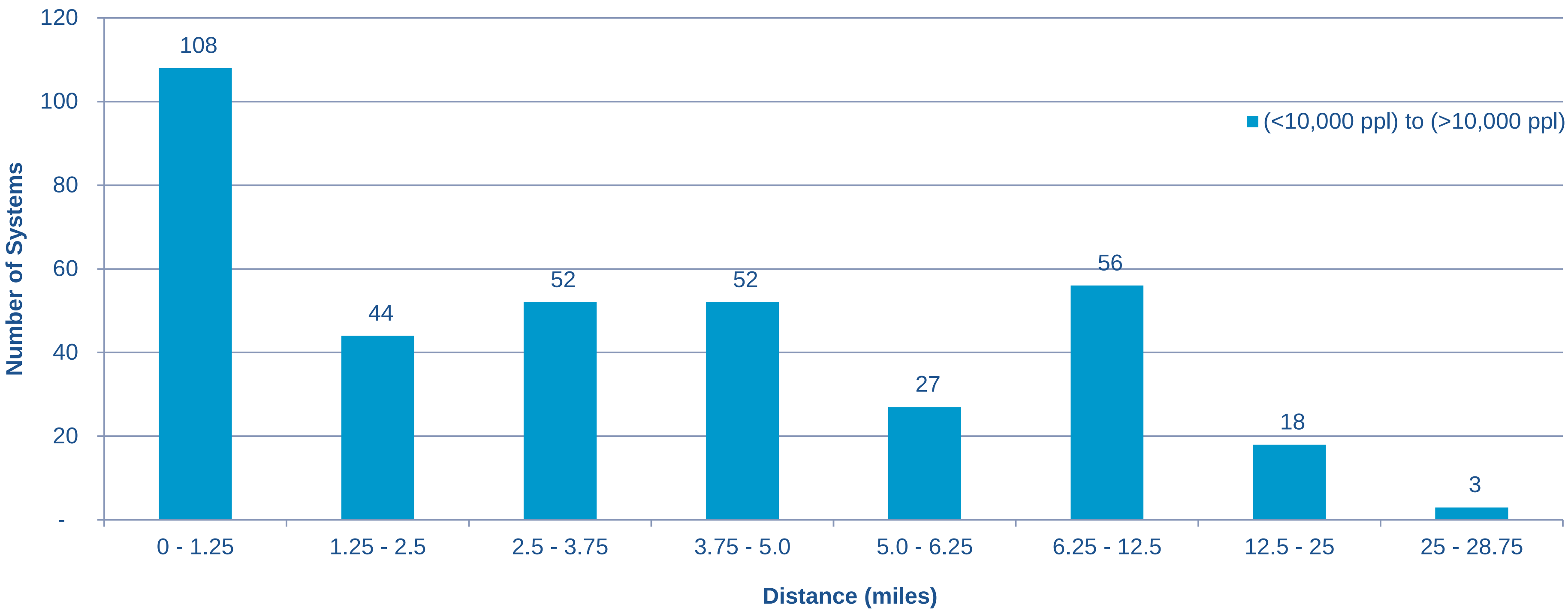
System Distribution by Population Served



System Size	Population Served	% of Total Population on CWS
Very Large	1,230,047	52%
Large	860,892	37%
Medium	155,497	7%
Small	68,246	3%
Very Small	32,852	1%

Piped Connection to an Existing System

The Minimum Distance from a Small System to a Larger System [Source: PICME 2010]



Removal Technologies

Source: Siemens

- Ion Exchange
  - Nitrate displaces chloride on anion exchange resin
  - Resin recharge with brine solution
  - Limitations: sulfate, resin fouling, disposal
- Reverse Osmosis
  - Water molecules pushed through membrane
  - Contaminants left behind
  - Limitations: membrane fouling, pretreatment, disposal

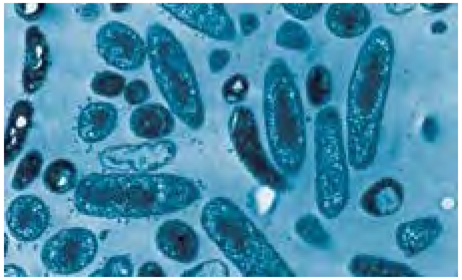
Source: Dow Chemical

- Electrodialysis
  - Electric current governs ion movement
  - Anion and cation exchange membranes
  - Limitations: operationally complex, disposal

Source: PC Cell

Reduction Technologies

- Biological Denitrification



Source: AnoxKaldnes

  - Bacteria transform nitrate to nitrogen gas
  - Anoxic conditions
  - Requires electron donor (substrate)
  - Limitations: lack of U.S. full scale systems, substrate requirement, post-treatment (filtration, disinfection)

- Chemical Denitrification

Source: Hepure Technologies

  - Metals reduce nitrate to ammonia (typically)
  - Zero-valent iron (ZVI)
  - Catalytic denitrification
  - Limitations: pilot studies only, reduction to ammonia, dependence on temperature and pH

Treatment Options

Table i Comparison of Major Treatment Types[1]

Concerns	IX	RO	EDR	BD	CD
High Nitrate Removal					
High TDS Removal					
Arsenic Removal					
Radium and Uranium Removal					
Chromium Removal					
Perchlorate Removal					

Priorities	IX	RO	EDR	BD	CD
High Hardness Not a Major Concern					
Reliability					
Training/ Ease of operation					
Minimize Capital Cost					
Minimize Ongoing O&M Cost					
Minimize Footprint					
Industry Experience					
Ease of Waste Management					

Good	→	Poor	Unknown (blank)

1 Ion Exchange (IX), Reverse Osmosis (RO), Electrodialysis Reversal (EDR), Biological Denitrification (BD), Chemical Denitrification (CD). This table offers a generalized comparison and is not intended to be definitive; there are notable exceptions to the above classifications.

POU/POE

From CDPH Emergency Regulations, as of December 21, 2010,

"…a public water system may be permitted to use point-of-use treatment devices (POUs) in lieu of centralized treatment for compliance with one or more maximum contaminant levels… if;

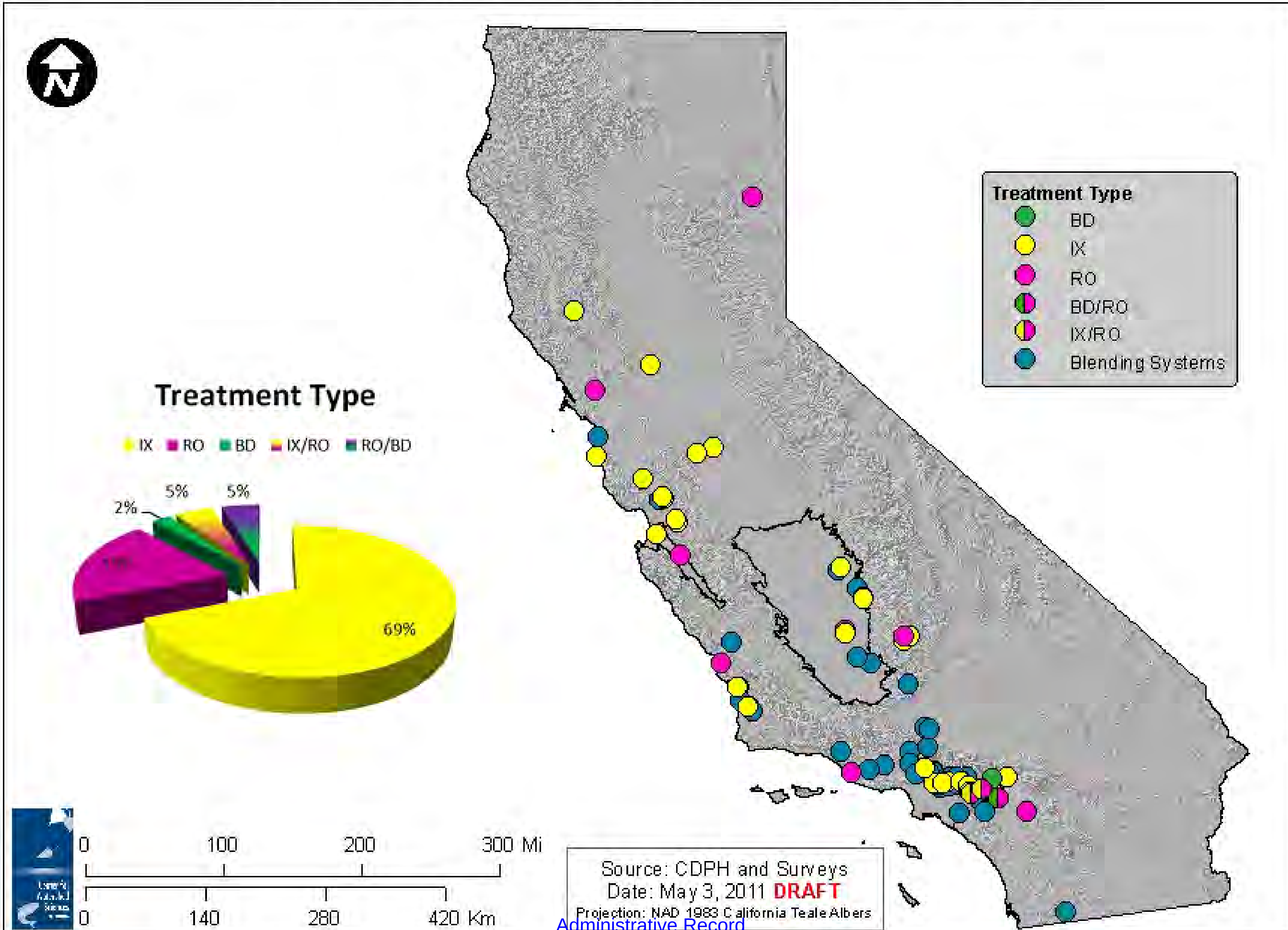
(1) the water system serves fewer than 200 service connections,

(2) the water system meets the requirements of this Article,

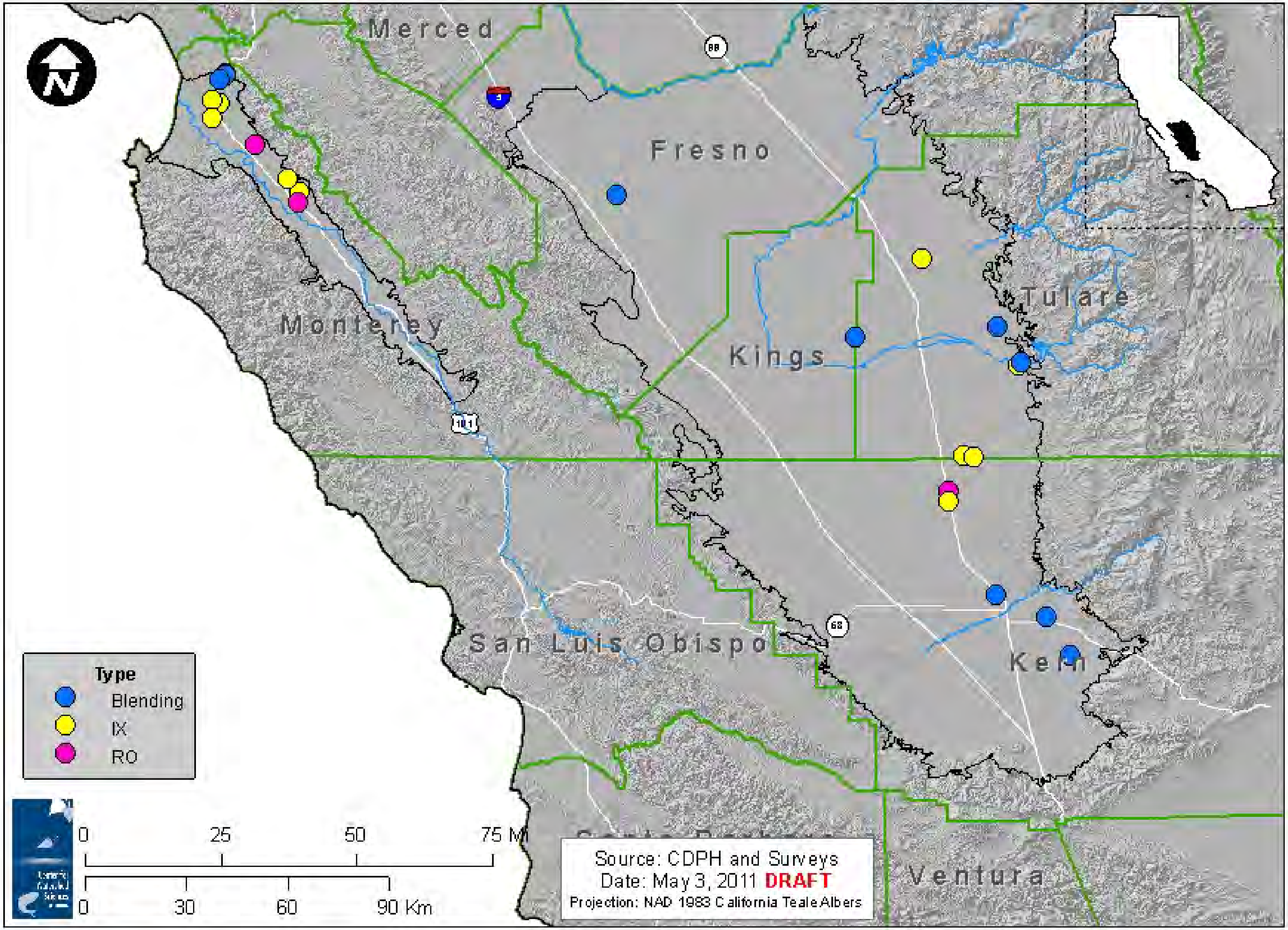
(3) the water system has demonstrated to the Department that centralized treatment, for the contaminants of concern, is not economically feasible within three years of the water system's submittal of its application for a permit amendment to use POUs,

… no longer than three years or until funding for the total cost of constructing a project for centralized treatment or access to an alternative source of water is available, whichever occurs first…"

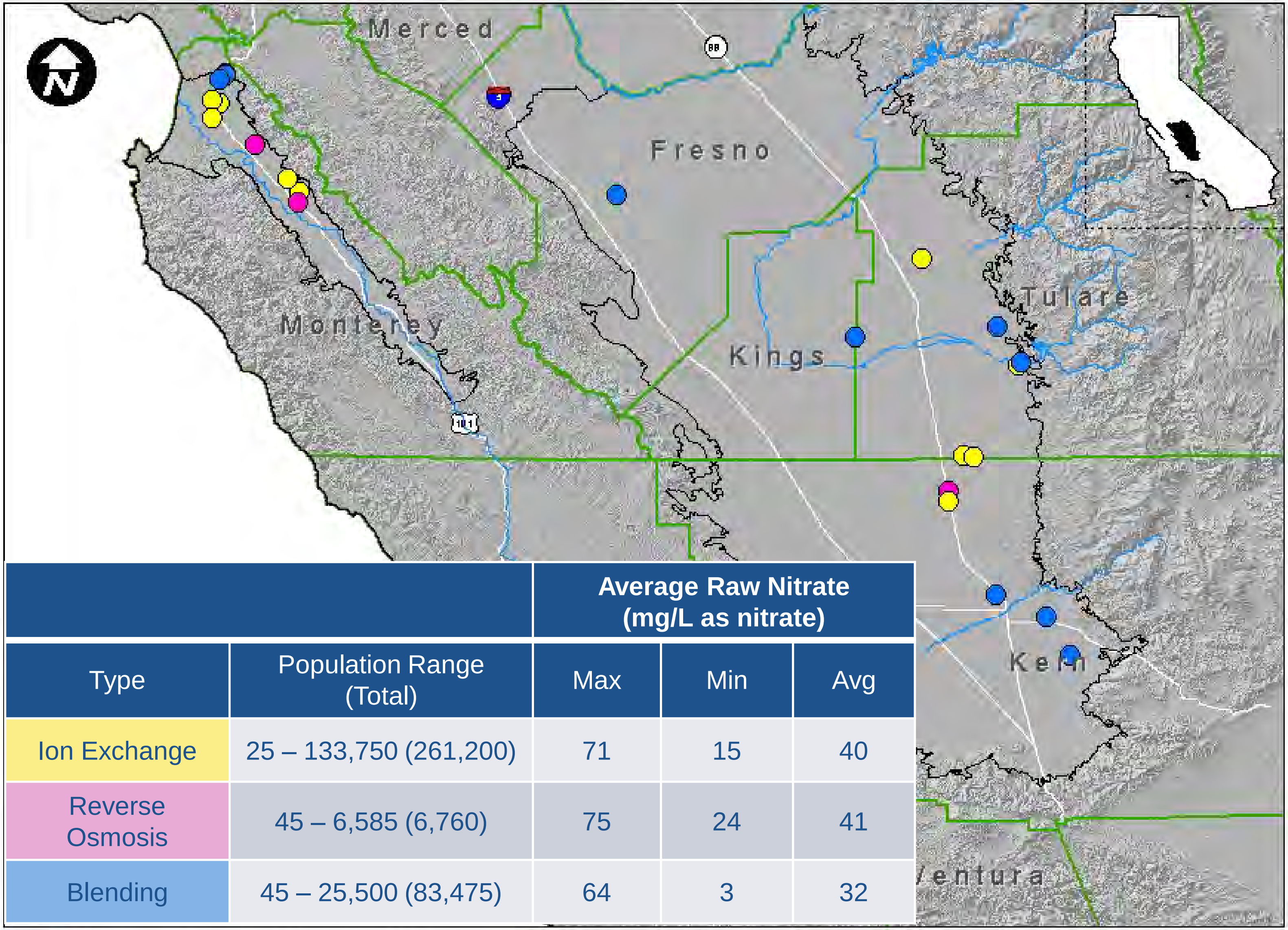
Systems Treating or Blending to Address High Nitrate Levels



Systems Treating or Blending to Address High Nitrate Levels



Systems Treating or Blending to Address High Nitrate Levels



		Average Raw Nitrate (mg/L as nitrate)		
Type	Population Range (Total)	Max	Min	Avg
Ion Exchange	25 – 133,750 (261,200)	71	15	40
Reverse Osmosis	45 – 6,585 (6,760)	75	24	41
Blending	45 – 25,500 (83,475)	64	3	32

Overview

Water Quality Data

Assess nitrate occurrence
Characterize water quality

Vulnerable Populations

Characterize vulnerable populations
Locate disadvantaged communities

Solutions

Alternative water supply options
Nitrate treatment options

GOAL

Assess options to address the nitrate problem with consideration of location, water quality, system size, feasibility and cost

Example Costs for Alternative Supply Options

Option	Example	Est. Cost
Providing POU systems with Maintenance for **Three Years** for Potable Uses Only	A 1,000 person community	$ 200,000
Providing Bottled Water for **One Year** for Potable Uses Only	A 1,000 person community	$ 400,000
New 1,400 ft Well	Ducor Community Services District	$ 700,000
New 700 ft Well + Pump + Tank + Distribution System	Plainview Mutual Water Company	$ 2,500,000
Consolidation	Several Small Communities North of Lamont to the East Niles Community Service District	$ 6,500,000

Costs by Technology

Ion Exchange (IX)
Pro: Generally the least expensive
Con: Brine disposal

Reverse Osmosis (RO)
Pro: Wide treatment capabilities
Con: More expensive

Biological Denitrification (BD)
Pro: Long term sustainability
Con: Limited application

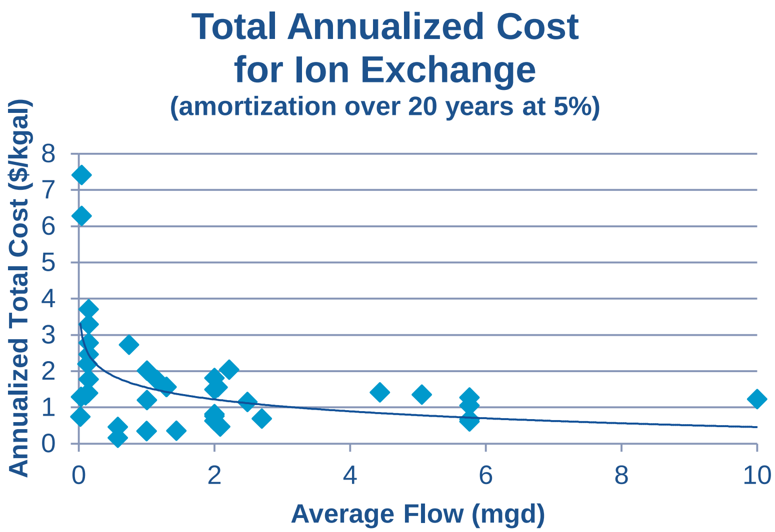
Type	Annualized Capital Cost ($/kgal)	Annual O & M Cost ($/kgal)	Total Annualized Cost ($/kgal)
IX – Literature	0.08 – 0.80	0.15 – 1.25	0.34 – 2.04
IX – Survey	0.06 – 0.94	0.12 – 2.63	0.41 – 2.73
RO – Literature	0.81 – 4.40	1.22 – 2.00	2.32 – 5.86
RO – Survey	0.19 – 3.16	1.15 – 16.16	1.35 – 19.16
BD	0.47 – 0.83	0.30 – 0.94	0.92 – 1.56

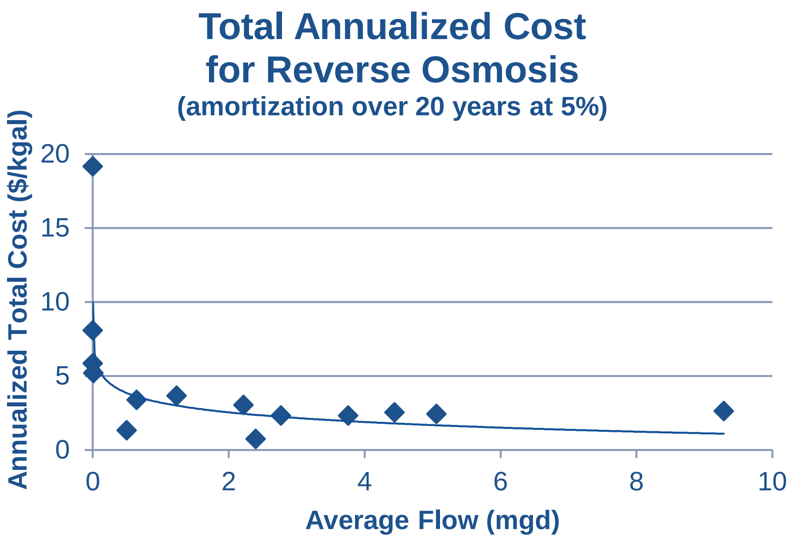
Treatment costs are unique to individual systems based on:

*system size
*co-contaminants
*location
*treatment type
*blending options
*disposal options
*nitrate level
*seasonal variation
*others…

Costs by System Size

Centralized Treatment

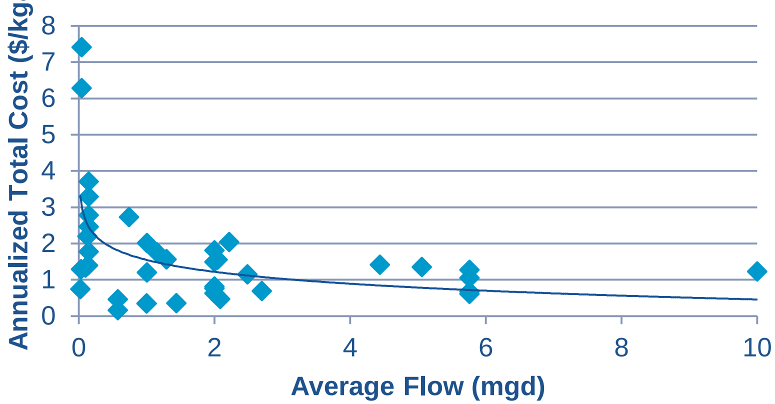




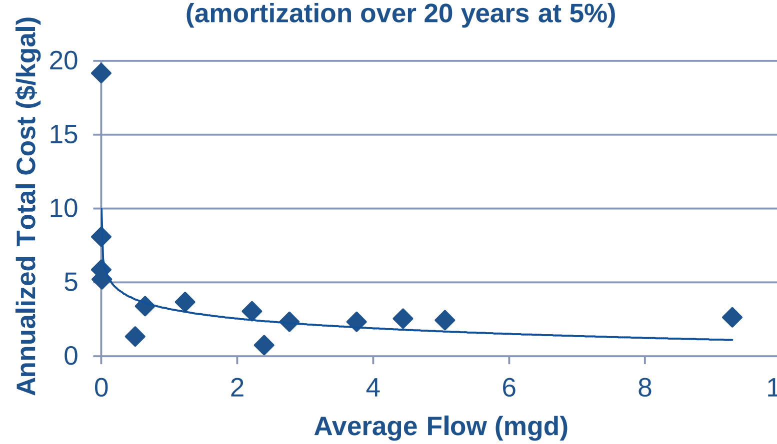
Costs by System Size

Centralized Treatment

Total Annualized Cost for Ion Exchange
(amortization over 20 years at 5%)



Total Annualized Cost for Reverse Osmosis
(amortization over 20 years at 5%)



Point-of-Use

	Upfront Investment	Annual Costs	Comments
Ion Exchange	$660-$2425	Salt costs ($3.30-$4.40/bag)	Requires disposal of brine waste, high sodium levels
Reverse Osmosis	$330-$1430	$110-$330/yr + electricity	Requires filter replacement, high maintenance, lower water recovery

From (Mahler et al., 2007)

Observations on Current Funding Sources

- Sustainability and sufficiency of main sources unclear
- No funds for Ag investment in nutrient mgt/NO_3 reduction
- Ag water use efficiency funds to fund NO_3 loading reduction?
- Many small pots of $ for drinking/wastewater for small communities and DACs, scattered, difficult to access
- Nitrate drinking water contamination investment needed statewide, based only on 2010-11 fundable list > $4/person for capital costs only
- No funds for community water supply regionalization feasibility studies and planning

Regulatory Instruments (RI): Assumptions and Limitations

- Focus on regulatory instruments to manage nitrate emissions from non-point sources, especially agriculture
  - Instruments could address emissions from both point and non-point sources

- Qualitative analysis
  - Ranking of regulatory instruments along criteria
  - Analysis rooted in previous case studies
  - Future work could quantitatively compare these instruments

- Analytical dimensions
  - Cost-effectiveness, administrative feasibility, information requirement revenue raising
  - Many potential criteria

RI: Analytical Criteria

- Cost-effectiveness
  - Abatement (nitrate reduction) costs to meet a nitrate standard
  - How can a standard be achieved at the least cost?
- Administrative costs
  - Bulk of these costs are monitoring and enforcement
  - Costs vary depending on the unit of regulation – few industries or many individuals
  - Future work could quantitatively compare these instruments
- Information Requirements
  - What information is needed to implement these regulatory tools?
- Revenue Raising
  - Regulatory instruments and funding options overlap
  - Is a regulatory instrument also a source a funding?

Instruments evaluated

- Technology mandate (non-market instrument)
  - Example: Management practices for pesticides
- Performance standard (non-market instrument)
  - Example: The dairy regulatory program nutrient management plan, which requires the ratio of N applied to N harvested to be less than 1.65
- Cap and trade (market-based instrument)
  - Example: Sulfur dioxide markets in the U.S. to address acid rain; AB 32
  - Overall, a 10% reduction in fertilizer use (5% reduction ha A and 15% ha B)
- Fee (market-based instrument)
  - Example: Mill tax; tax on fertilizer that induces a 10% reduction in fertilizer use
  - With C&T choose a quantity (market determines price) and with a fee choose a price (market determines quantity)

Instruments evaluated

- Information disclosure
  - Example: Consumer confidence reports on drinking water quality (SDWA)
- Liability rules
  - Example: Superfund
- Payment for water quality
  - Analogous to payment for ecosystem services
  - Public pays farmers to not release nitrates or farmer pays gov't to release nitrate
  - Example: Drinking water in NYC; Perrier and Evian; REDD
- Redesignation of beneficial use
  - Example: Change beneficial use from drinking to another standard

What can be regulated?

- Fertilizer use
  - Regulation on input
  - Advantages: Low administrative costs; low information requirements
  - Disadvantages: Regulating input rather than "pollutant" (i.e. gasoline tax rather than a tax on emissions)

- Nitrate leachate concentration within recharge area of drinking water source
  - Regulation on actual pollutant flux into groundwater recharge area
  - Advantages: Regulate the pollutant of interest; achieve policy objective
  - Disadvantages: High administrative costs (non-uniform mixing); high information requirements; uncertainty in assessing recharge area for specific source

- Other ideas?
  - Nitrate emissions concentration – concentration of nitrate emissions released into source (not account for non-uniform mixing)
  - Nitrate emissions volume – volume of nitrate emissions released into source

Funding Source: Assumptions and Limitations

- Focus on sources of funding
  - UCD team does not address how the money should be allocated
  - Treatment, remediation, alternative water supplies
- Provide a list (with explanation) of potential options
  - No analytical criteria – any comments?
  - Create different incentives
- Qualitative exercise
  - Provide examples of funding options
- Comments

Funding Options: Water Fees

- Fixed monthly fee on drinking water for CA residents
- Volumetric fee on drinking water for CA residents
  - Option: Fee for “high quantity” consumers
- Tax on irrigated water
- Fixed fee on agricultural water
- Fertilizer or nitrate tax
- Groundwater pumping fee
- Fee on bottled water (similar to recycling fee)

Funding Options: Other Fees

- Fertilizer tax
- Nitrate emissions tax
- N leachate tax
- Food tax
- Agricultural property tax
- Auctioned fertilizer or nitrate permits (cap and trade)
- Septic tank discharge
- Waste water discharge
- State water bonds

Moving forward

- Final comments on regulatory instruments
  - Analytical criteria
  - Instruments evaluated
- Suggestions on funding sources
  - Analytical criteria
  - Other funding sources
  - Alternative approaches
- Contact: kkjessoe@ucdavis.edu

Key Messages

- Nitrate problem will likely worsen and not improve for several decades
- Largest regional sources are agricultural fertilizers and animal wastes; other sources are locally relevant
- Nitrogen loading reductions possible, but will take decades to benefit drinking water sources
- Short-term solutions are blending, treatment, and alternative water supplies
- Treatment is unaffordable for most small communities
- Promising funding options, incentives, and regulatory tools are identified
- Incoherence and inaccessibility of data prohibit better and continuous assessment